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## Computational Model Builder for Multi-Dimensional Models

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<b>14. ABSTRACT</b> This report summarizes Kitware's efforts to provide ERDC with a suite of pre-processing tools that could support the various hydrological-based simulation workflows used by several laboratories. This effort has been named Computational Model Builder (CMB) and includes applications for processing LiDAR (PointsBuilder), creating appropriate geometric scenes (SceneBuilder), creating appropriate model topology and simulation information such as materials and boundary conditions (ModelBuilder), and manipulation of meshes (MeshViewer). In addition tools to support both the Environmental Simulation Effort (ES) and the Engineered Resilient Systems (ERS). Various ParaView extensions to support ERDC's post-processing needs (including PinCurve) were also developed.					
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## Introduction

The emphasis of this contract was to develop tools for supporting the various hydrological-based simulation workflows being used by ERDC. These workflows included ground water and surface water models and were eventually expanded to include more complex environmental simulations. The resulting suite of tools is referred to as Computational Model Builder (CMB) and has been used in various workflows including ADH, Proteus, and several ecologically based simulations. These tools include:

- PointsBuilder – provides processing of various scanned based data such as LiDAR
- SceneBuilder – provides the ability of creating geometric scenes of the domain being modeled
- GeologyBuilder – provides some based geologic modeling capabilities such as boreholes and cross-sections
- ModelBuilder – provides the ability of creating the appropriate topological description of the geometric domain as well as the ability to model and assign various materials, boundary conditions, and other information necessary to define the simulation
- MeshViewer – provides the ability to view and modify the analysis mesh
- ParaView – provides HPC-based post-processing capabilities.

Figure 1 shows the main hydrological workflow supported in CMB.

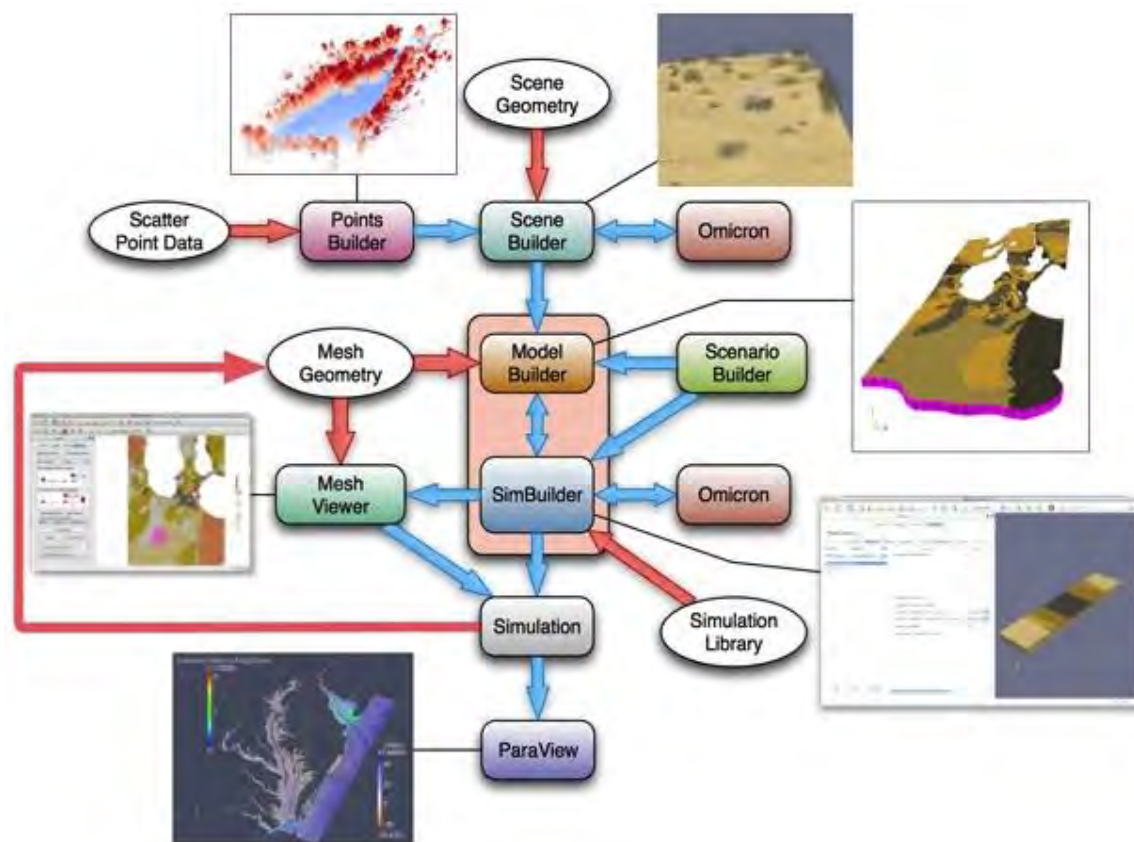


Figure 1 - CMB's Hydrological Workflow

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In the last years of the project, tools were developed to support ERDC's Environmental Simulation (ES) effort as well as ERDC's Engineered Resilient Systems (ERS) effort.

## Computational Model Builder Suite

This section will show some of the advances of CMB made during this contract period.

CMB's architecture is based on an open-source set of libraries and frameworks as shown in Figure 2. It leverages ParaView's architecture and provides client/server capabilities. As a result the GUI frontend of a CMB application can run on the user's desktop while the computationally intensive server could run in a HPC environment such as Garnet. In addition CMB also provides a plugin mechanism allowing workflow specific functionality to be included at runtime.

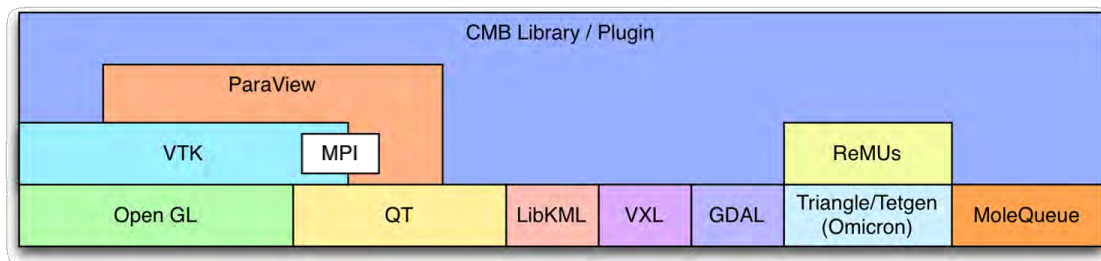


Figure 2- CMB's underlying architecture

CMB supports MacOS, Windows and Linux. The core of CMB is available under BSD open source license and ERDC has unrestricted access to the entire code repository.

## PointsBuilder

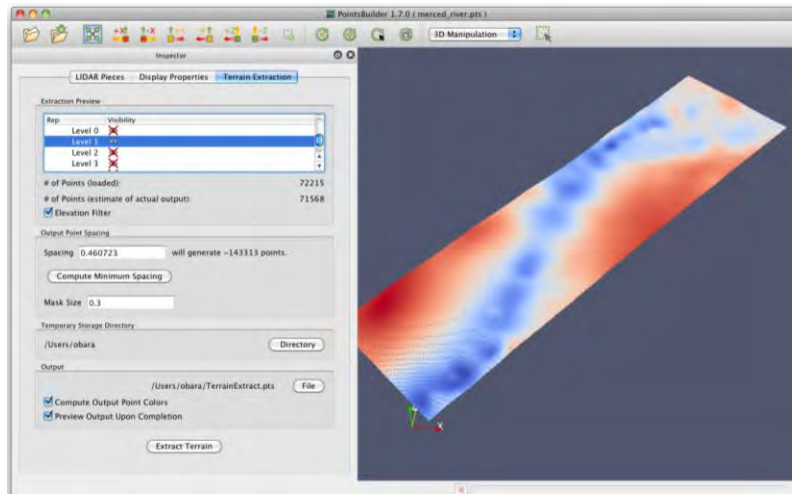


Figure 3: CMB's PointsBuilder Applications

As previously mentioned, PointsBuilder was developed as a tool for processing point cloud based models produced by various scanning methodologies, in particular LiDAR. The data can be from a single scan or the result from multiple scans. The tool provides various mechanisms for selecting subsets of the point cloud including threshold and elevation filtering as well as by applying user-defined planar contours. The main capabilities of the tool are described in the following sub-sections.

### Automatic Terrain Extraction

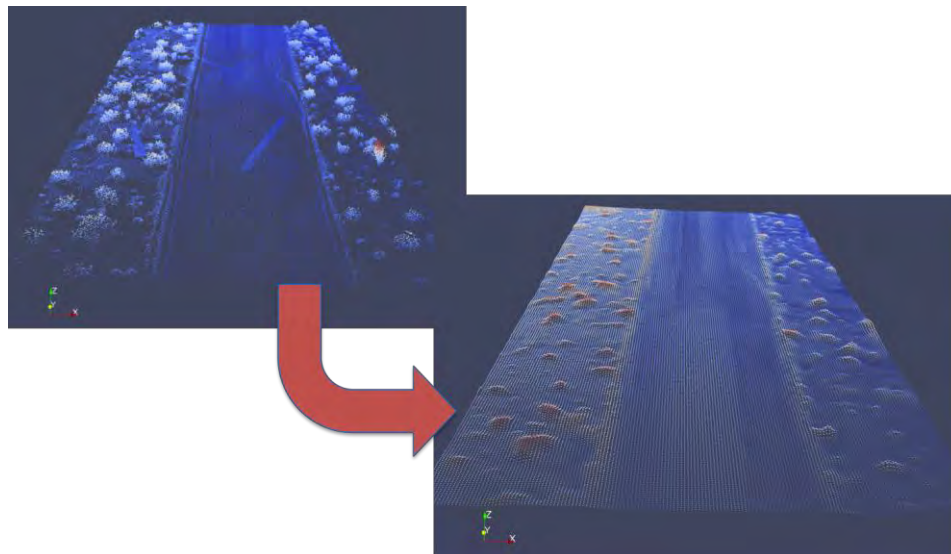


Figure 4: Example of Terrain Extraction in PointsBuilder

PointsBuilder's Terrain Extraction function provides the ability to remove unwanted details such as vegetation and calibration targets, as well as the ability to fill in missing terrain as shown in Figure 4.

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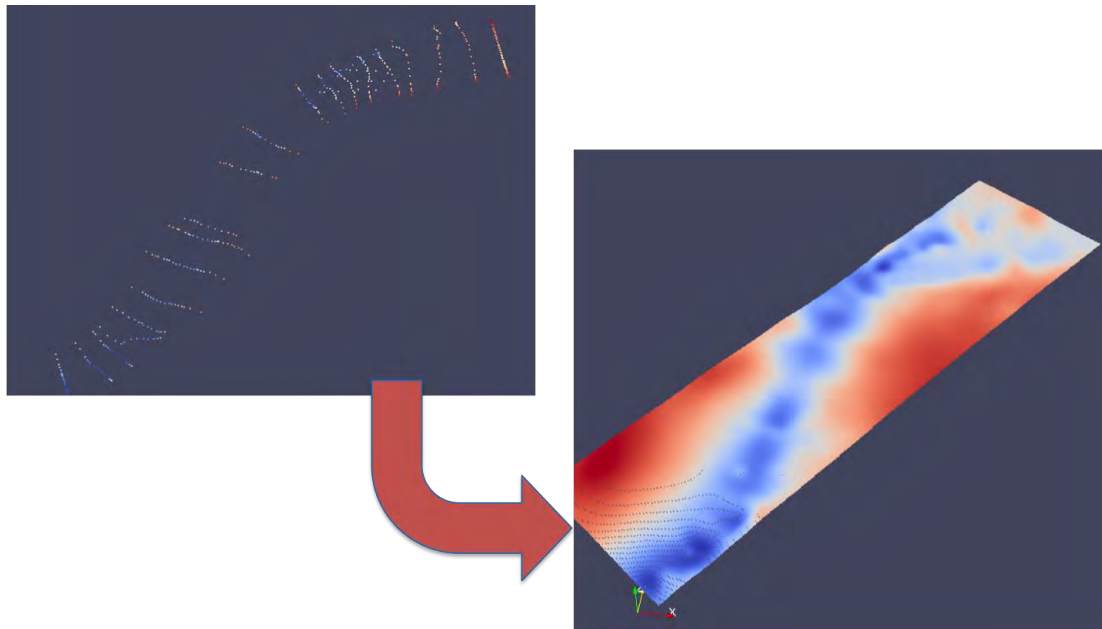


Figure 5: Applying terrain extraction on Merced River LiDAR

The terrain extraction mechanism can be applied on vary sparse clouds as shown in Figure 5. In this example the coarse LiDAR represented Merced River on the left colored by elevation. The image on the right is the result of the extraction also colored by elevation.

## Apply Displacement Functions

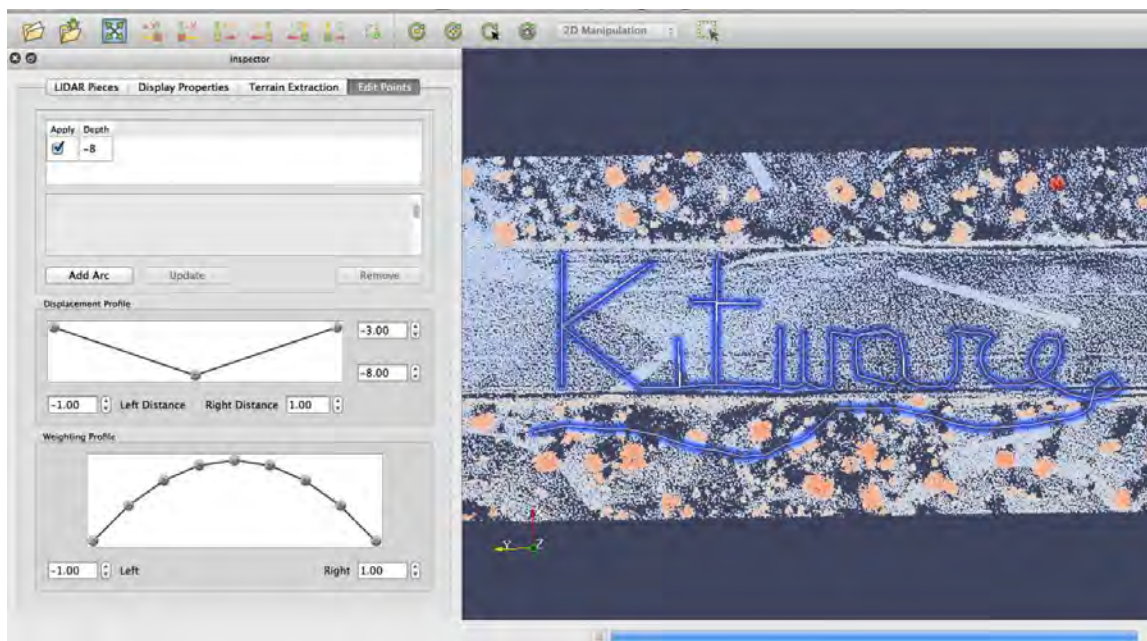


Figure 6: Apply Point Displacement Functions in PointsBuilder

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In addition to terrain extraction, the tool also provides the ability to display the points along an user-defined contour. The user associates a cross-section displacement function along with a weighted blending function as shown in Figure 6.

## SceneBuilder

SceneBuilder allows the user the ability to assembly geometric components to represent the geometric shape of the problem domain. The types of objects that can be imported include:

- LiDAR/Point Clouds
- Solids
- Polygonal Surfaces
- Triangulated Irregular Network (TIN) Surfaces
- Map Information
- Poly Files
- Shape Files
- VTK Data

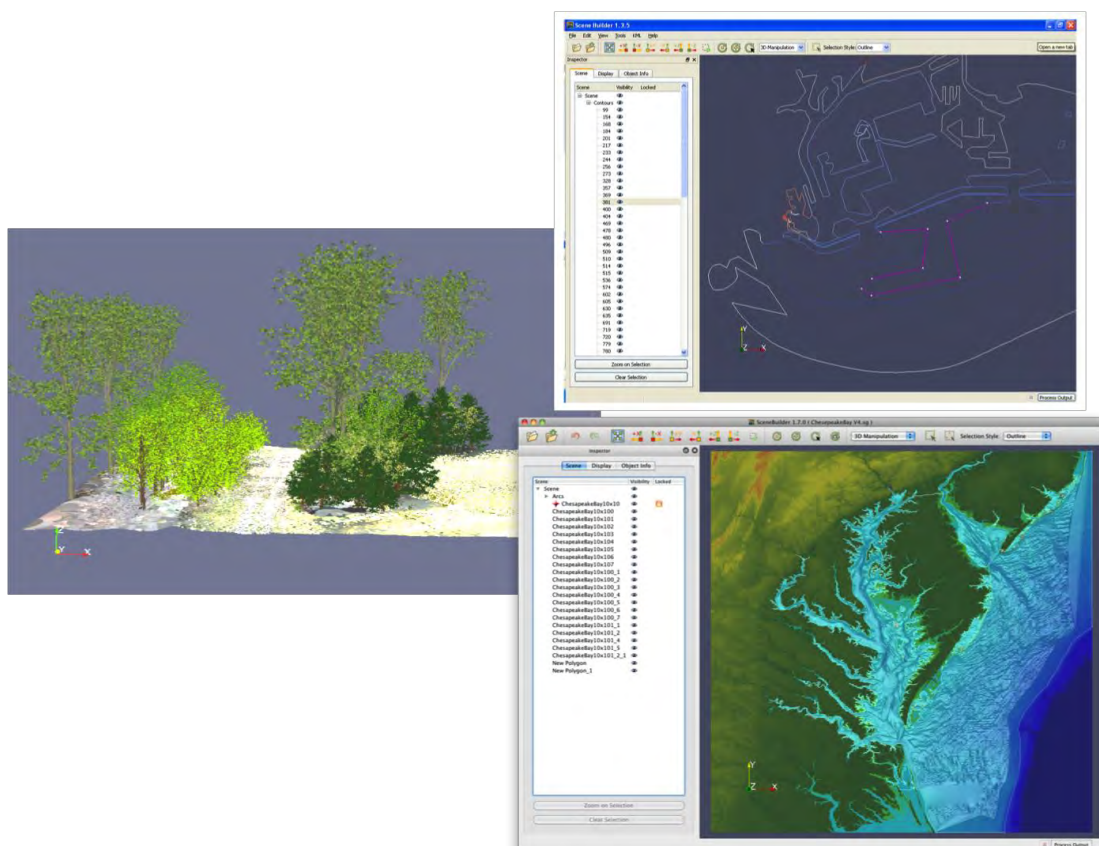


Figure 7: Examples of scenes created in CMB's SceneBuilder

Objects can be positioned, rotated, scaled, textured mapped, colored, and snapped to other objects in the scene. SceneBuilder also provides the ability to create VOIs, Ground Planes, Lines, Arcs, and 3D Glyphs as well as the displacement function capability for Points and TINs similar to functionality provided in PointBuilder. SceneBuilder also provides the ability to stitch TIN Surfaces to form closed solid shells as shown in Figure 9. The plan-view boundaries of the TIN surfaces need not be identical in order to be stitched.

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In terms of 2D capabilities, the tool provides automatic “Arc” extraction from Digital Elevation Models and the ability to construct planar surfaces from arcs as shown in Figure 10. Planar surfaces can also be extruded and stitched into a TIN surface as shown in Figure 11. Finally, SceneBuilder Interfaces with Omicron/Triangle Mesher to generate appropriate boundary representation (BRep) models that can be attributed and meshed for a simulation.

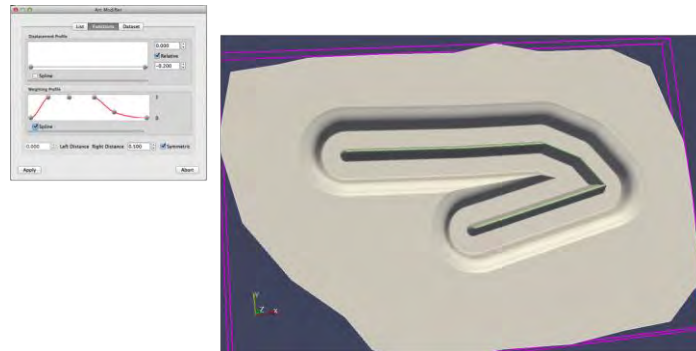


Figure 8: Displacement Operation performed on a TIN Surface

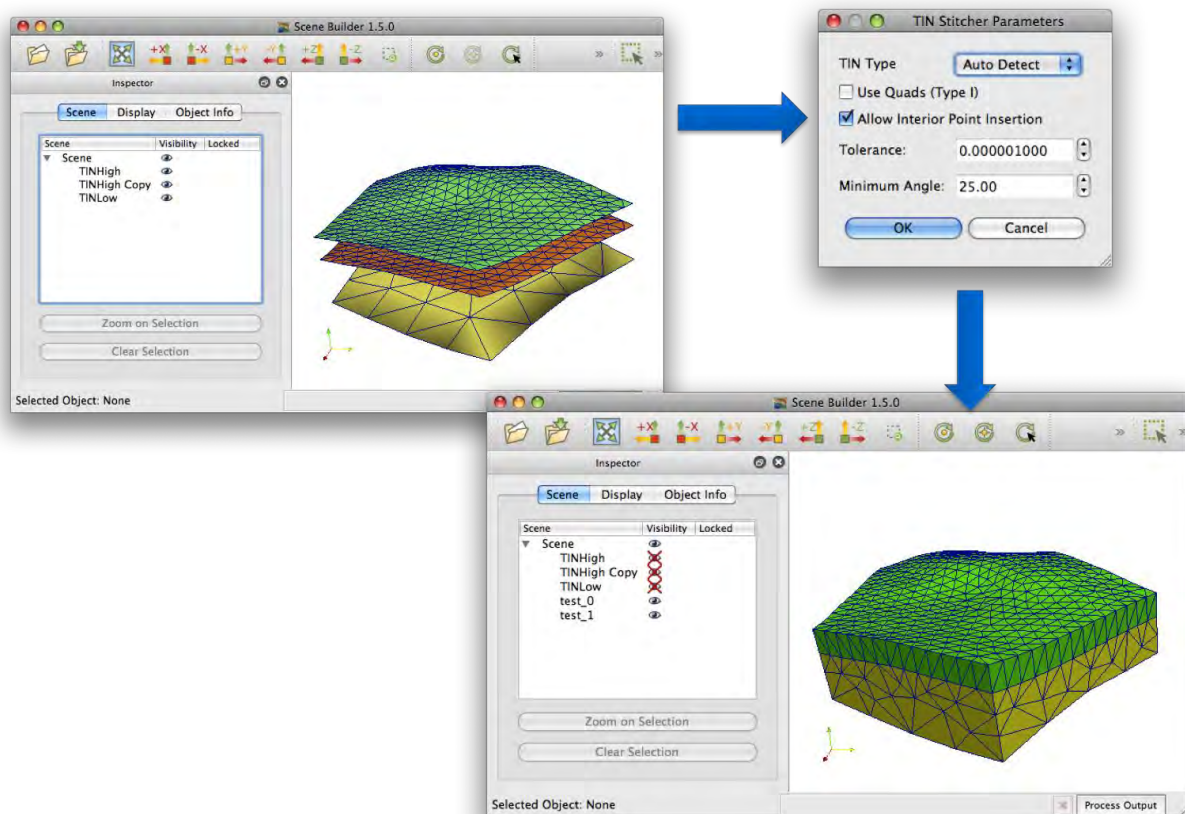


Figure 9: TIN Stitching in SceneBuilder

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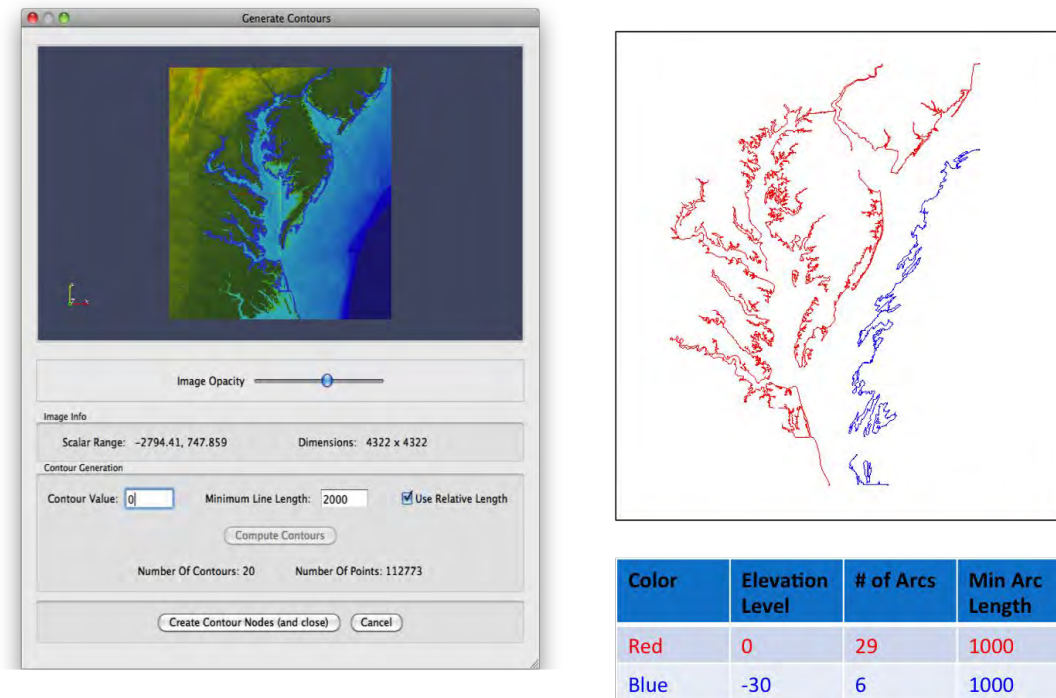


Figure 10: Automatic Arc Extraction using DEM of Chesapeake Bay

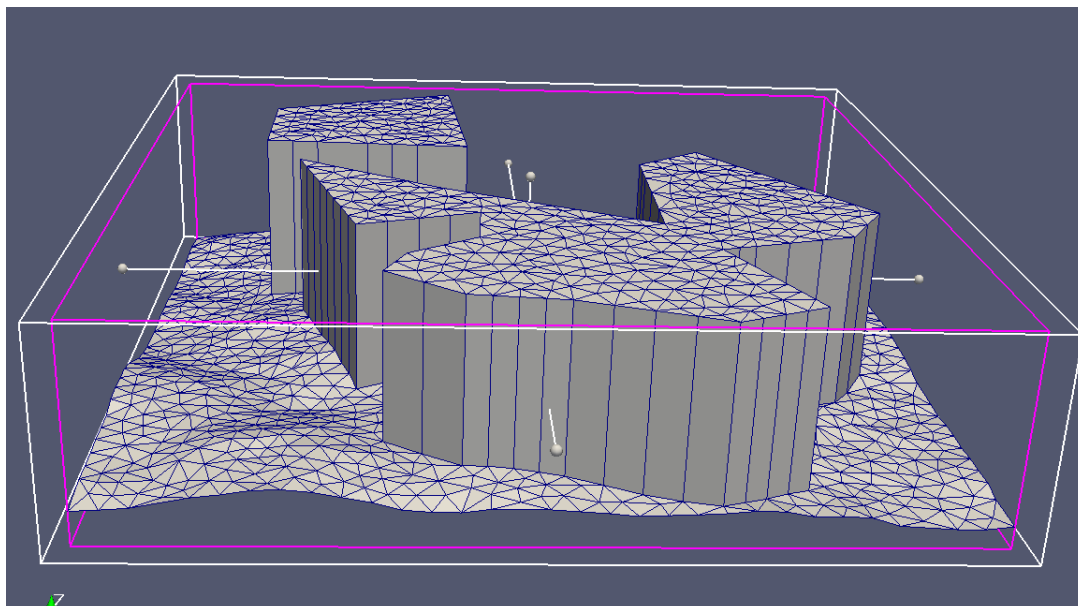


Figure 11: Example of planar surfaces extruded and stitched into a TIN terrain surface.

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## GeologyBuilder

GeologyBuilder is a customized version of SceneBuilder that adds the ability load in borehole and geologic cross-sections as shown in Figure 12.

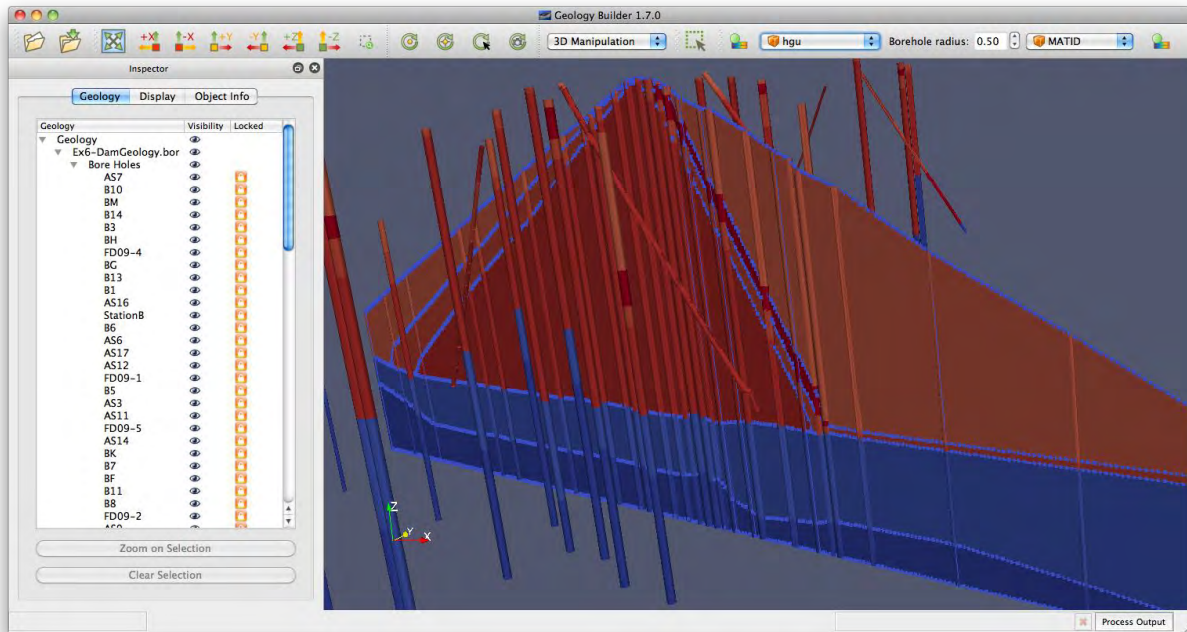


Figure 12: Example of boreholes and cross-sections loaded in GeologyBuilder

## ModelBuilder

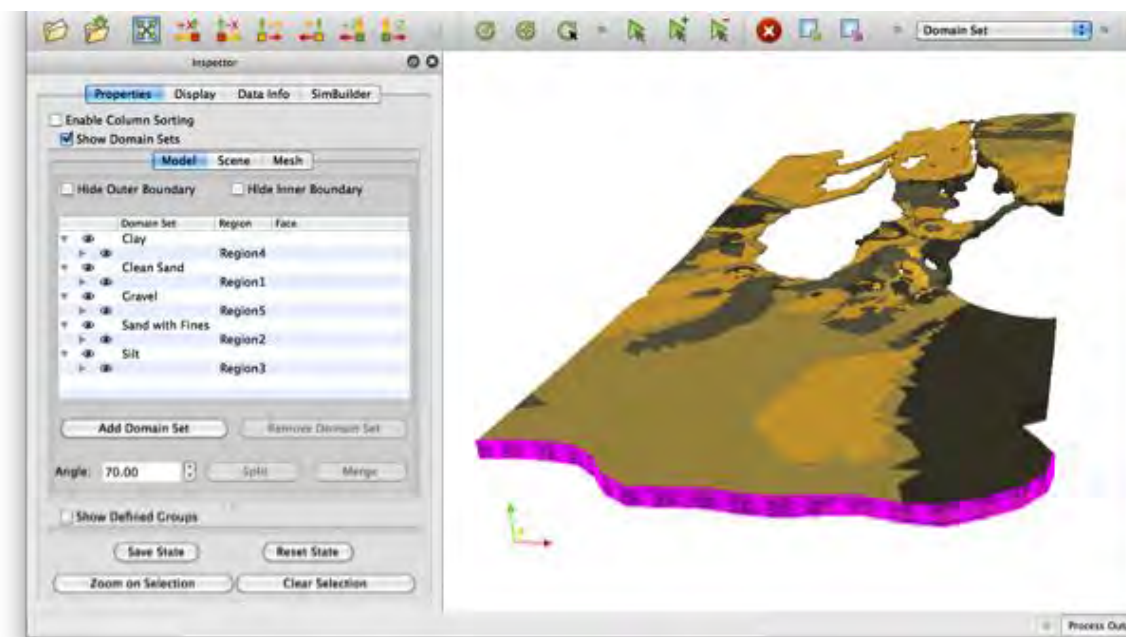


Figure 13: Example of ModelBuilder displaying a model of Pueblo

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ModelBuilder refines a BREP Model to provide topology suitable for Boundary Condition and Material Assignment. It provides various operations such as Split, Merge and Grow Selection and can process both discrete (Figure 13) and CAD-based geometry (Figure 14).

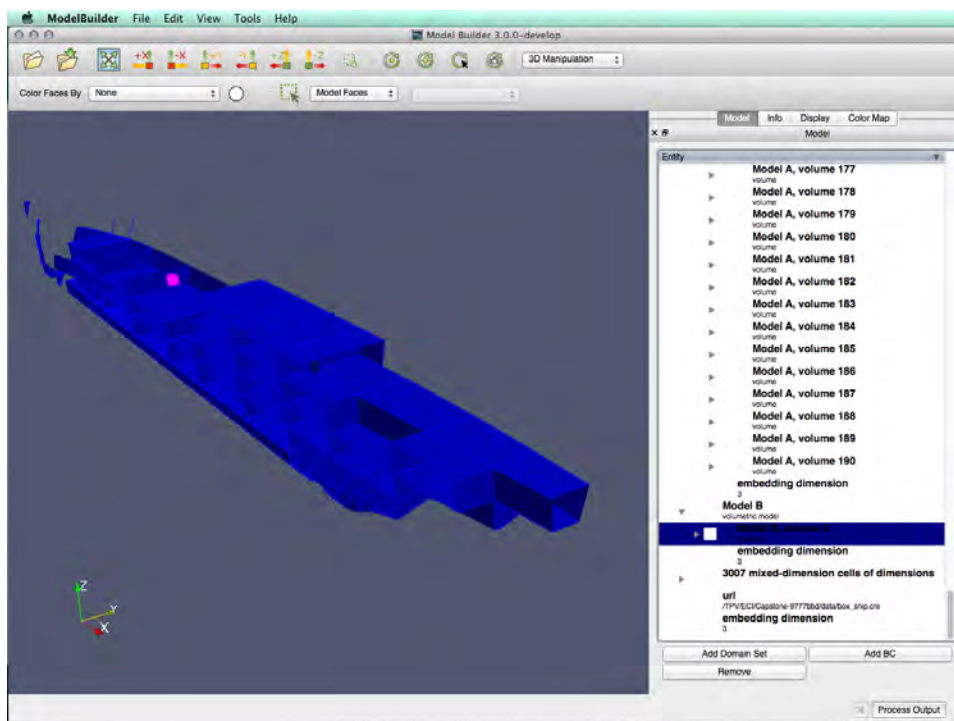


Figure 14: Example of a Capstone CAD model loaded into ModelBuilder

Users can group domains & boundary entities in order to better represent the conceptual/functional components of the model. ModelBuilder also provides the ability to extract a BREP from existing meshes. Through REMote Utilities (REMUS) services (also developed as part of CMB), ModelBuilder can interface with various meshes such as Omicron, Tetgen, Triangle, and Capstone to produce volumetric and surface meshes suitable for the simulation as shown in Figure 16 and Figure 17. The meshing process can be executed in a different processing thread or on a remote machine such as a HPC server. The basic architecture of REMUS is shown in Figure 15. In addition to the server component, new meshing processes, referred to as Mesh Workers can be easily added during runtime.

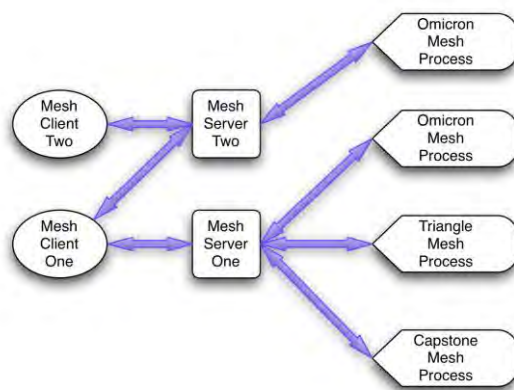


Figure 15: REMUS's architecture

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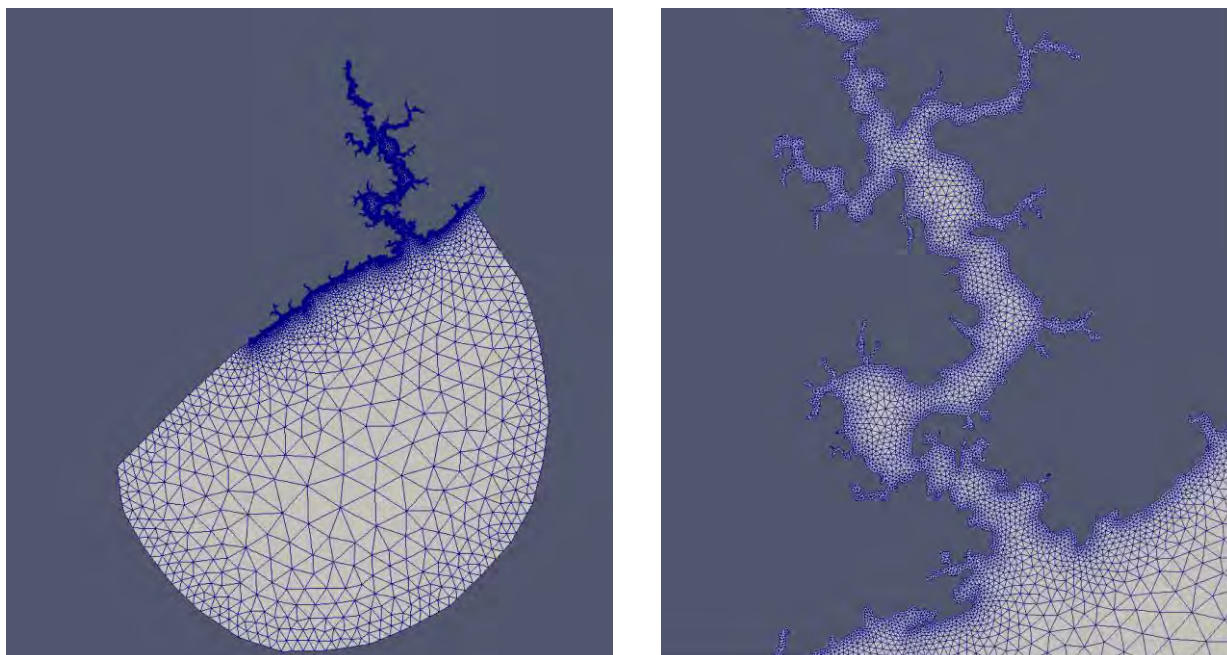


Figure 16: Example of using a Capstone REMUS Mesh Worker to generate a surface mesh of the New River near Camp Lejeune

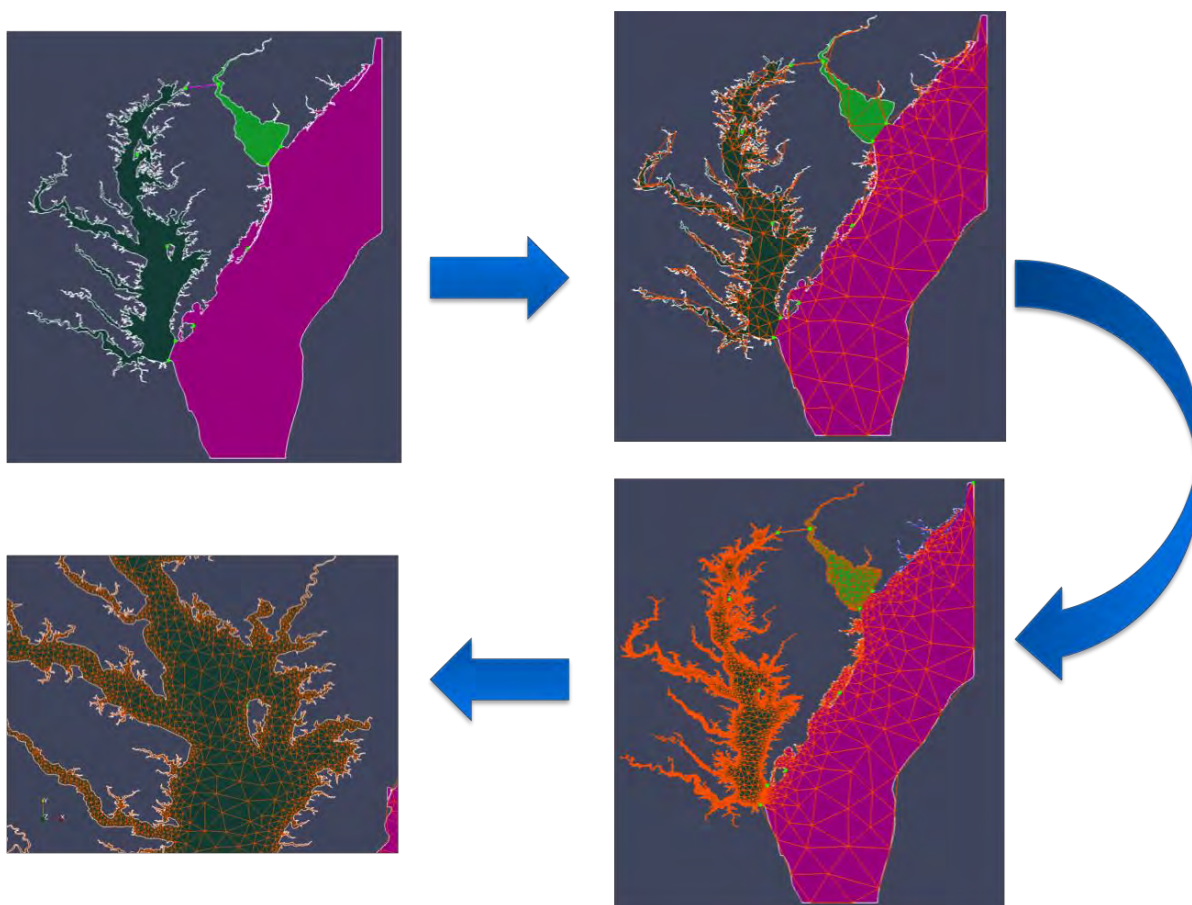


Figure 17: Surface meshing Chesapeake Bay using a Triangle-based working in REMUS.

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## SimBuilder

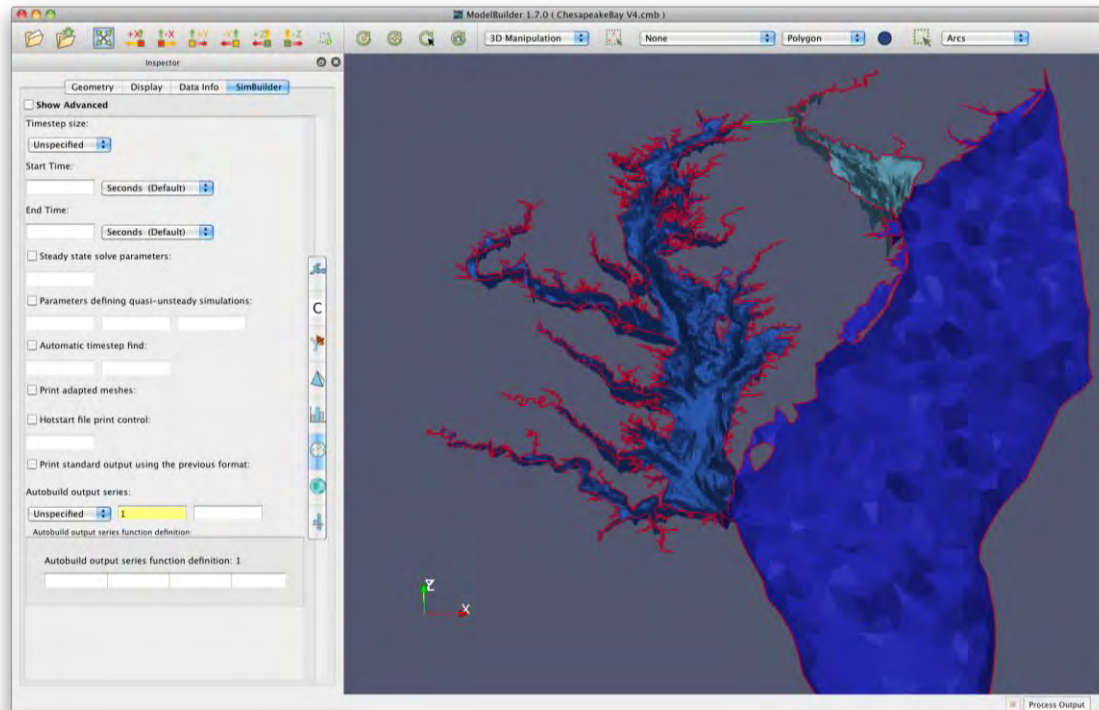


Figure 18: The SimBuilder Interface Panel (left) within ModelBuilder

SimBuilder is a sub-component of ModelBuilder and is responsible for creating and maintaining the non-geometric aspects of a simulation. This information can be assigned to model topology and groups defined in ModelBuilder. Since the information is assigned to the model and not the simulation mesh, multiple simulations (including those based on adaption) can be derived from the same simulation model. This information includes:

- Material Properties
- Boundary Conditions – both elemental and nodal
- Global Properties
- Simulation Control Parameters
- Functions

This simulation information is represented as an XML file and is initially created by the simulation expert. This “template” file describes the structure of the simulation information as well as constraints associated with the information such as:

- Types of topology the information can be associated to
- Value Ranges associated with the information
- If the values are discrete, enumerations can be associated with the values
- If the value must be constant or can be represented by an expression.

This template file is then used to create the appropriate attributes for a specific analysis. SimBuilder processes this XML description and automatically generates a custom UI inside of ModelBuilder as shown in Figure 19.

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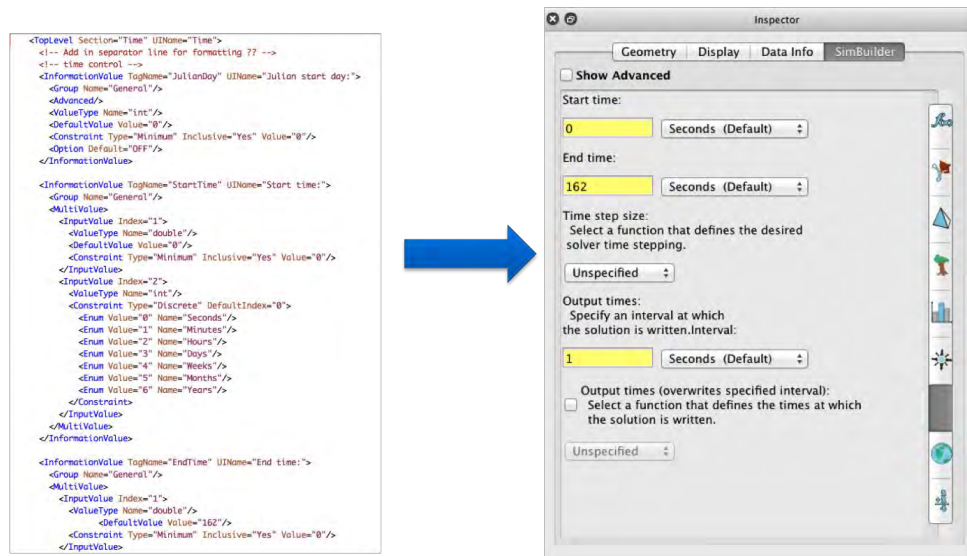


Figure 19: Example of XML Description of Simulation Information and its corresponding GUI Panel in SimBuilder

Finally SimBuilder also provides the ability to export both the analysis mesh and simulation information into a format required by the simulation itself as shown in Figure 20.

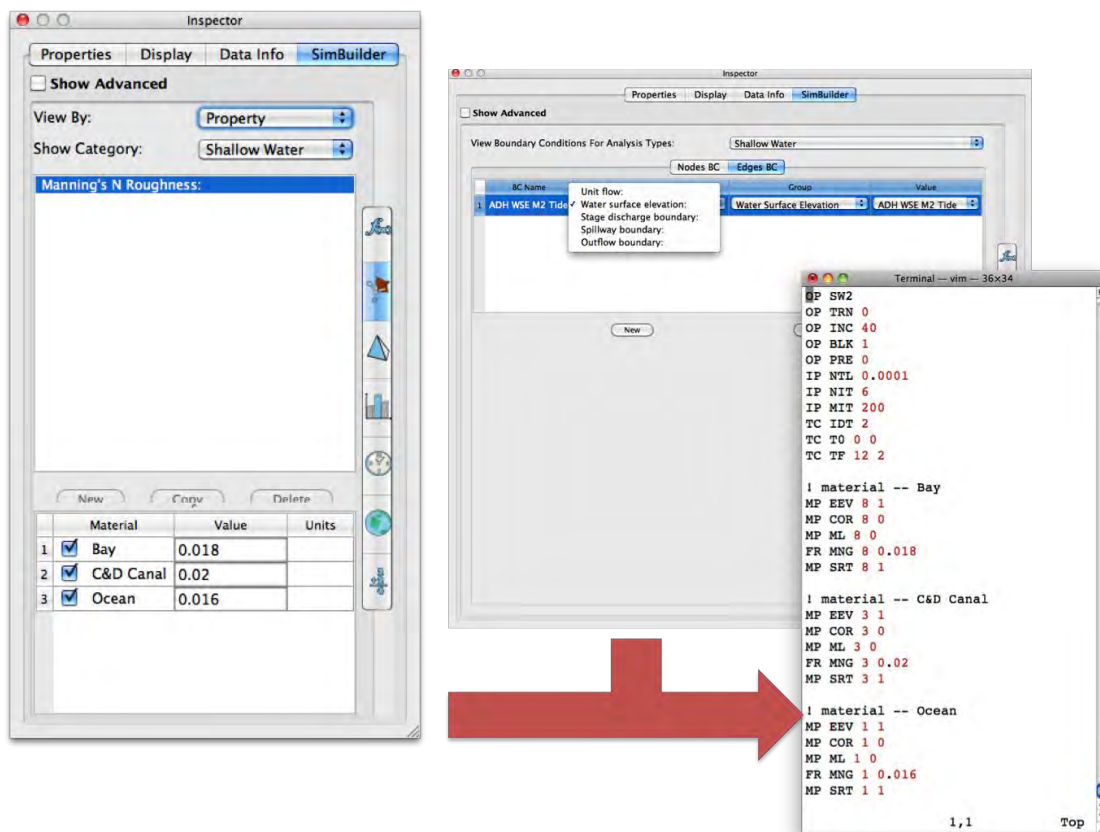


Figure 20: Converting CMB's simulation description into ADH Format.

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In terms of ERDC Simulation Workflows currently supported using ModelBuilder/SimBuilder these include:

- ADH Surface Water
- ADH Ground Water
- PT123
- Ecological Simulator
- Proteus

## MeshViewer

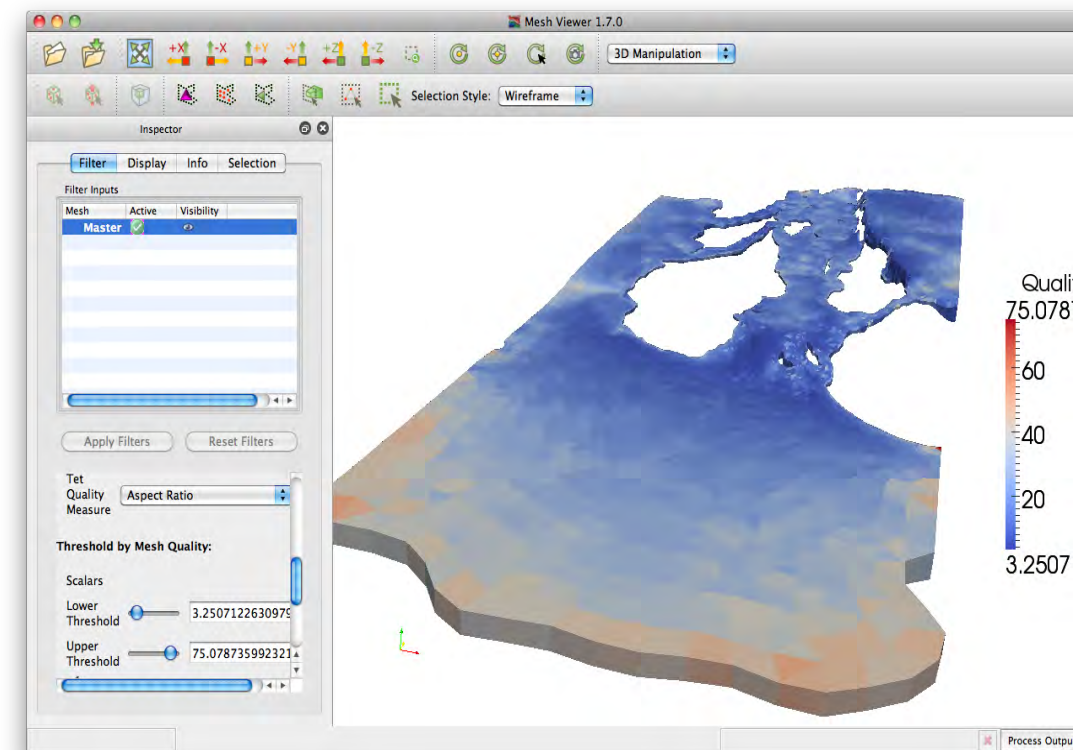


Figure 21: Example of an analysis mesh of Pueblo loaded into MeshViewer displaying mesh quality

The MeshViewer application provides the ability to inspect the simulation and the associated material properties assigned to the mesh elements. In addition it also provides the following functionality:

- Filtering based on mesh quality statistics as shown in Figure 21
- Mesh editing capabilities in terms of selection/material reassignment as shown in Figure 22.
- Ability to locally move nodal locations and perform meshing smoothing
- Ability to extract a sub-section of the mesh based on a selection as shown in Figure 23

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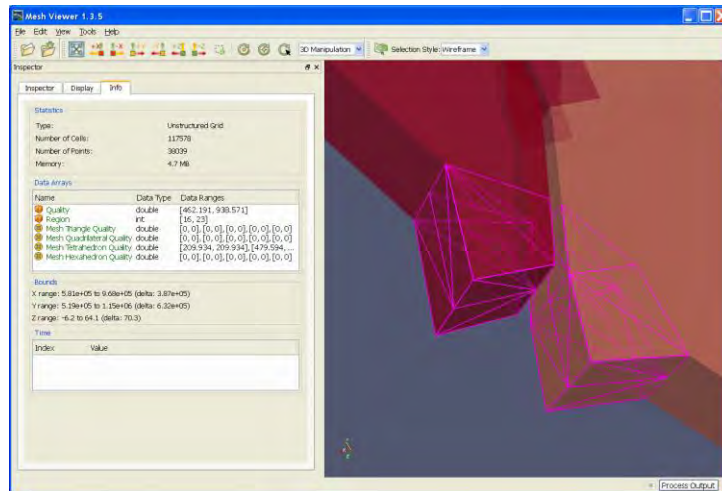


Figure 22: Selecting mesh elements in MeshViewer

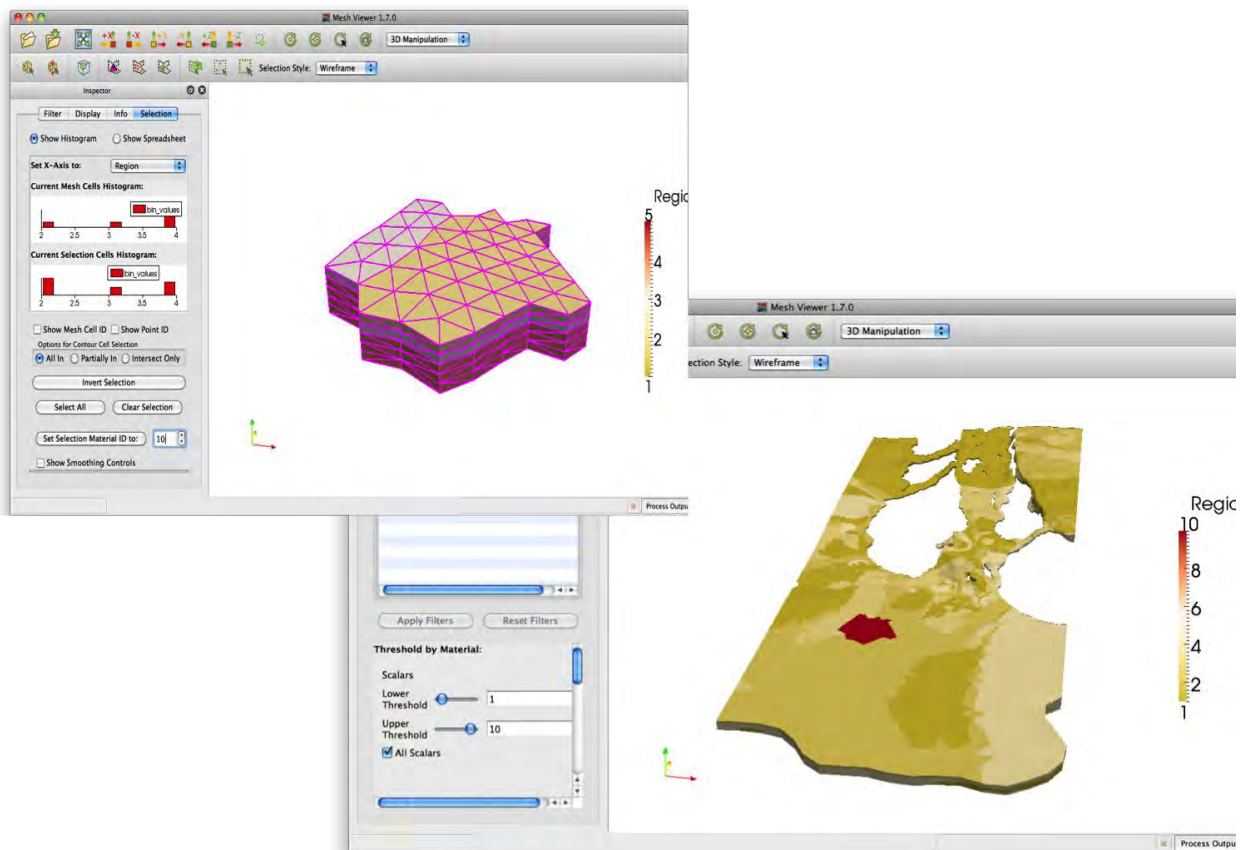


Figure 23: An example of extracting a subset from an analysis mesh.

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## DataBrowser

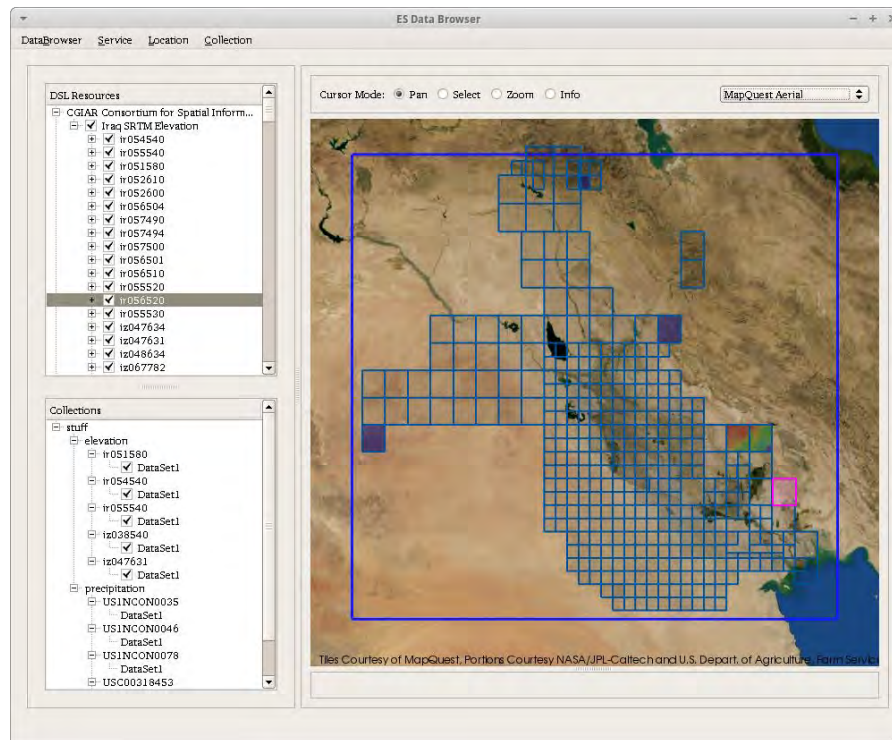


Figure 24: DataBrowser showing an area in Iraq as well as DSL Data Providers and Services that are available for the region displayed

The latest addition to CMB is DataBrowser, which is tool for accessing geo-spatial data stored in ERDC 's Data Services Library (DSL). Both DataBrowser and DSL are part of ERDC's Environmental Simulation Effort. As of the time of this report, DataBrowser provides the following capabilities

- Connecting to various geo-spatial map tile servers as shown in Figure 24
- For a given area of interest displaying which Data Providers and Services are applicable as well as geo-spatial locations that has data available. These locations can be either point locations or area defining as shown in Figure 25
- Fetching (through DSL) and display geo-registered data associated with a location as shown in Figure 26
- Plotting time series data associated with a location as shown in Figure 27
- Performing data filtering operation through DSL



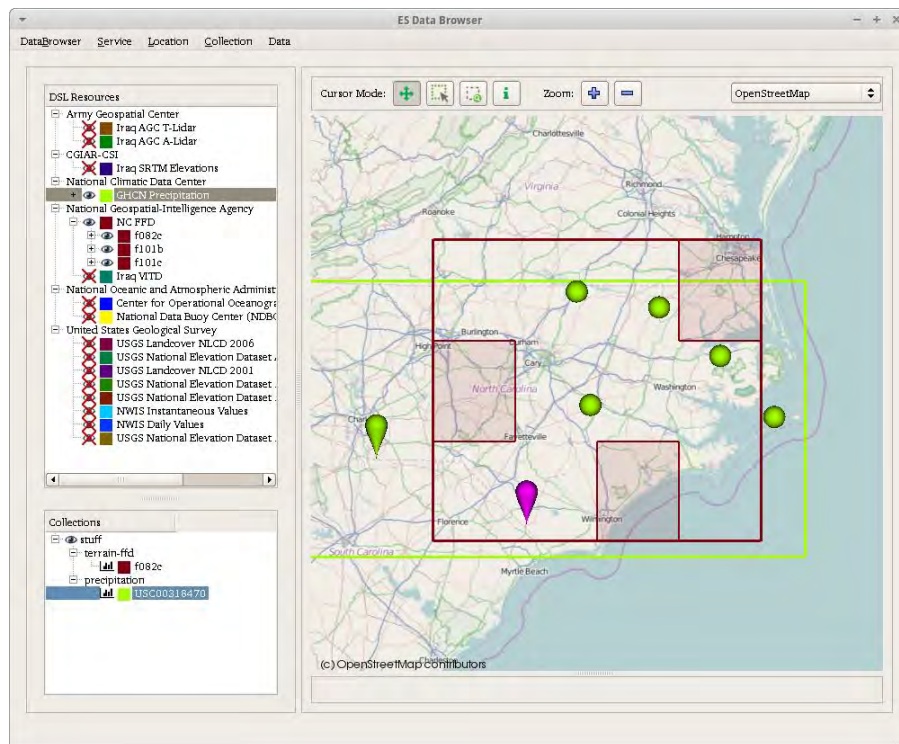


Figure 25: DataBrowser showing both point and area locations where data is available

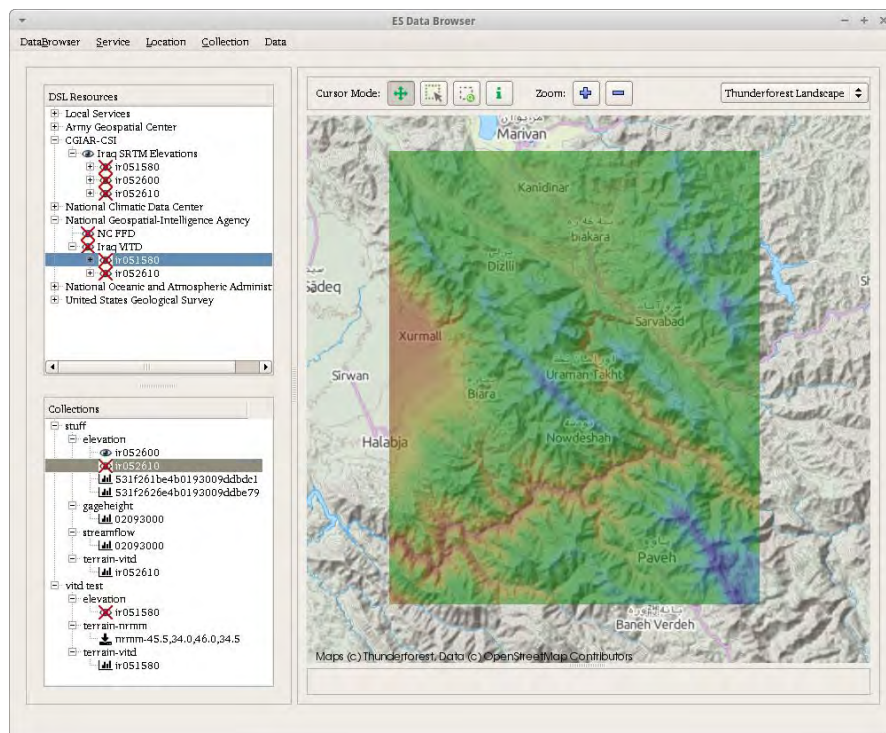


Figure 26: DataBrowser showing geo-registered elevation data in raster form.

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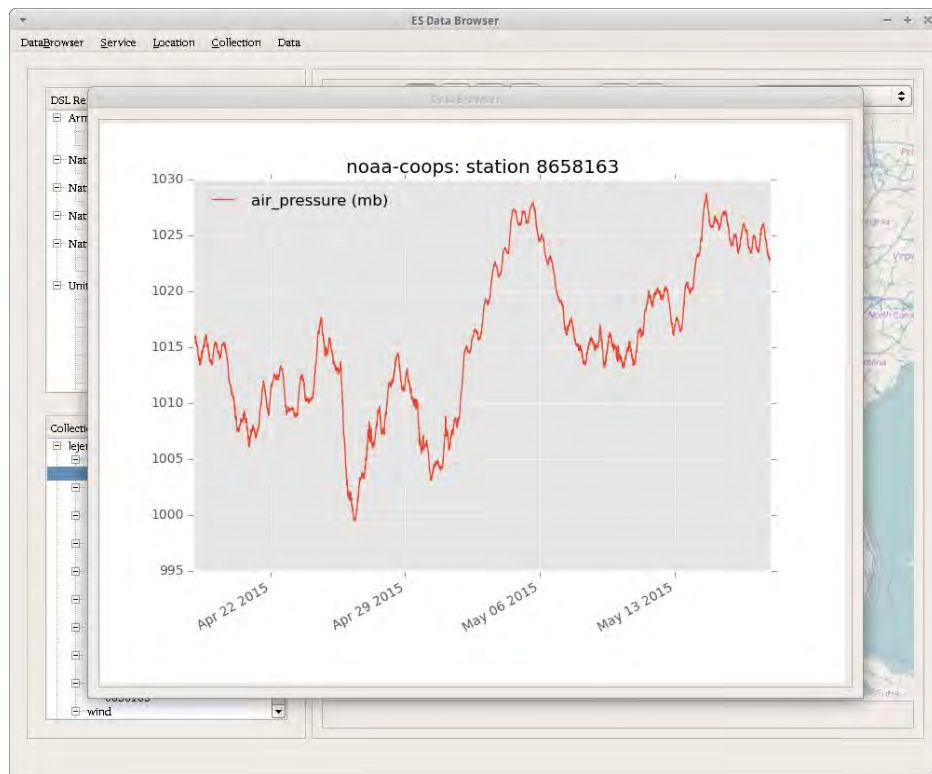


Figure 27: Plotting capabilities in DataBrowser for time-series data

## ParaView Enhancements

Throughout this project enhancements were made to the ParaView application in order to better support ERDC's needs to examples of this are supporting assessment classification of analysis results and supporting the PinCurve effort. In the case of assessment classification, new filters for determining the appropriate color banding of the data as well as providing discrete color table support as shown in Figure 28

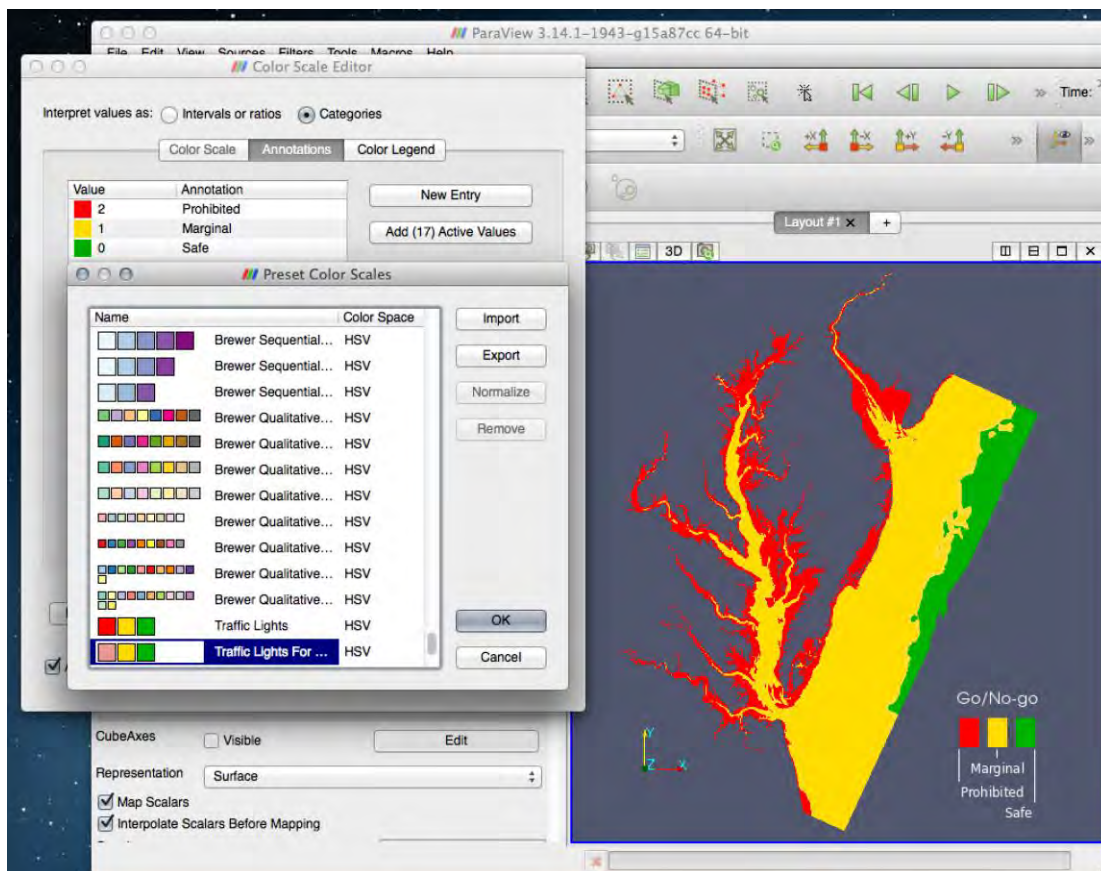


Figure 28: Assessment Support in ParaView

In terms of PinCurve support, the goal was to better support the post-processing workflow using ParaView in order to access more of ParaView's advance capabilities. This included hiding the normal pipeline workflow in ParaView and instead provides a workflow based more on the different materials involved in the simulation as shown in Figure 29.

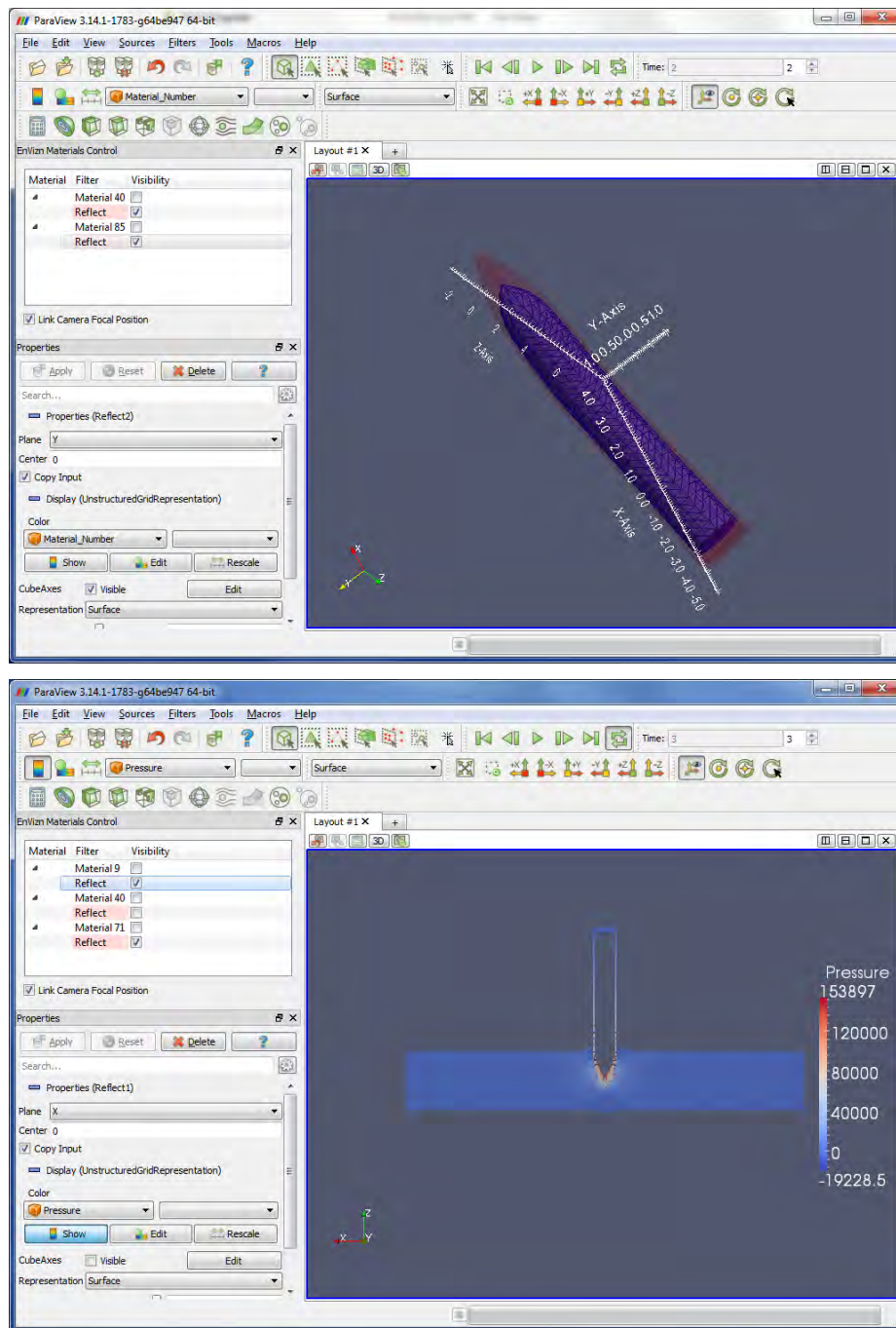


Figure 29: Examples of supporting the PinCurve workflow in ParaView

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## Engineered Resilient Systems (ERS) Support

Starting in 2014 and continuing in 2015 Kitware has been involved supporting the visualization needs of the Engineered Resilient Systems (ERS) effort within ERDC. Unlike the CMB effort, which has focused on desktop solutions, this effort required a web-based approach. The goal is to be able to intuitively view and assess large solution spaces. The tool allows the user to view the statically information associated with the solution space's parameters, as shown in Figure 30, and assign an assessment weighting to the parameters as shown in Figure 31.

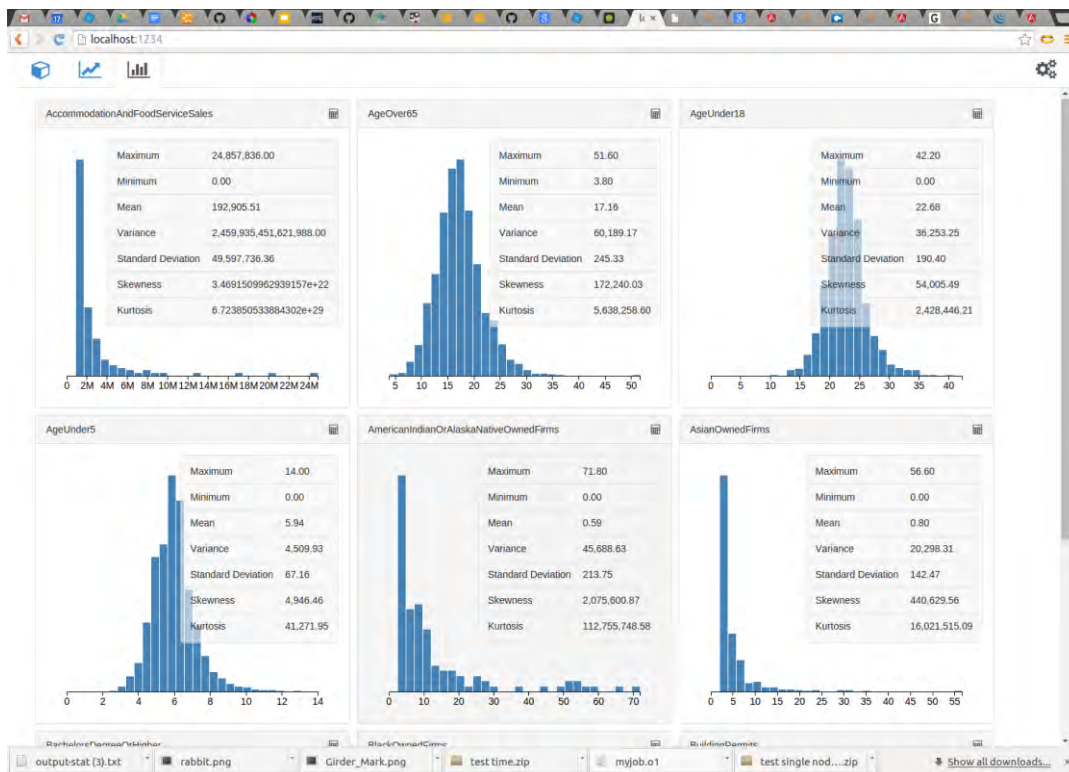
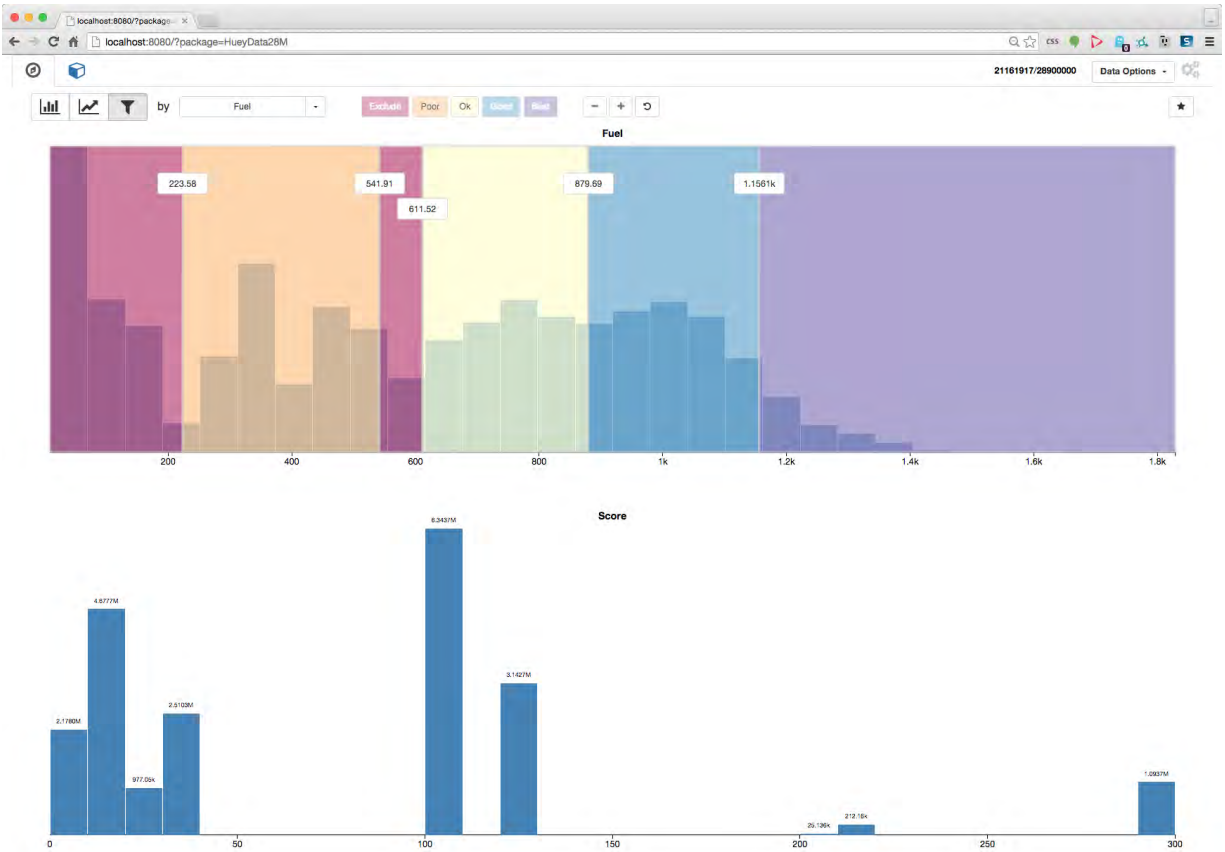


Figure 30: Showing statically information related to parameters associated with the solution space



**Figure 31: Assigning assessment weighting to the parameters associated with the solution space**

These assessment weightings can then be used to both color code the solution points as well as aiding in filtering the solution space. Figure 32 shows a scatter plot view within the tools showing millions of solution points.



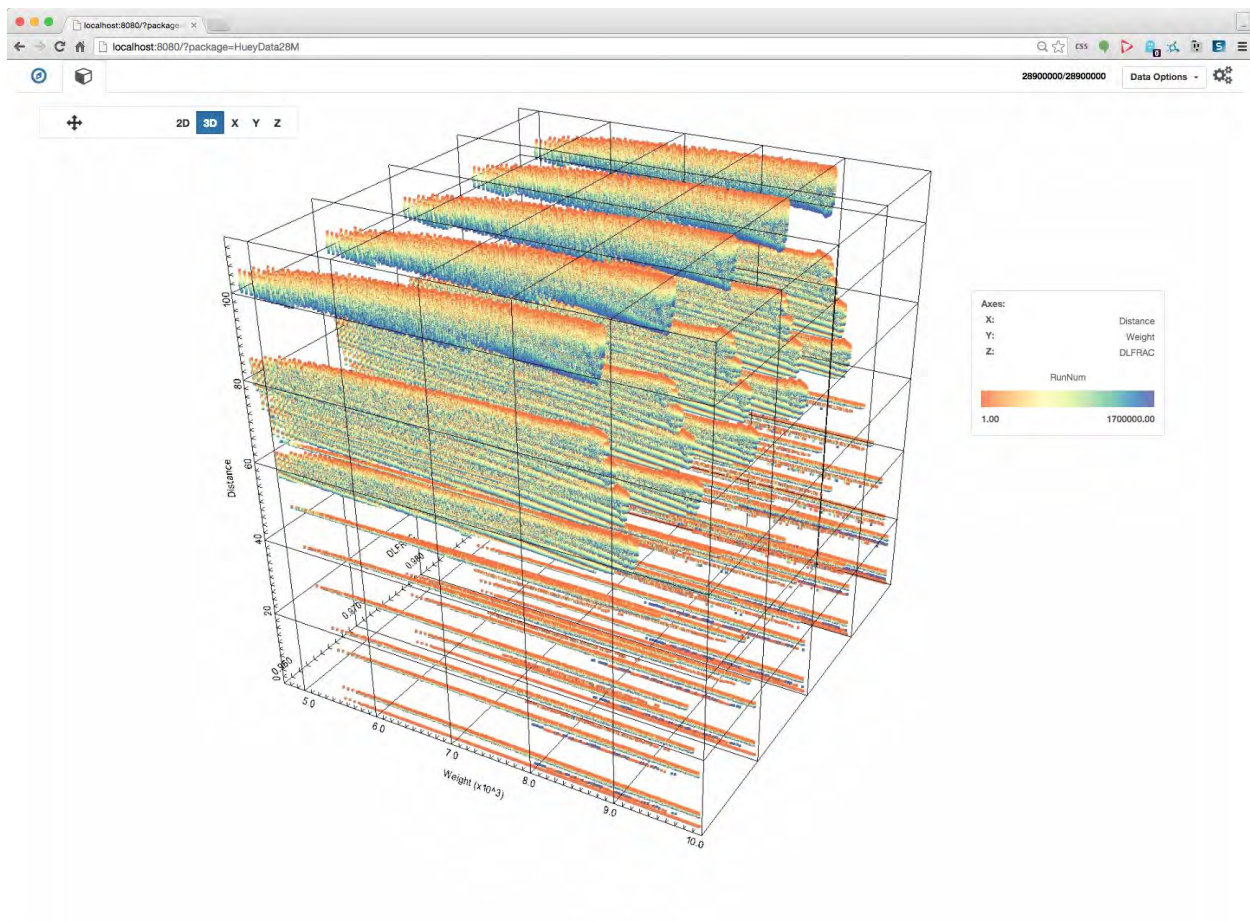


Figure 32: A scatter plot view of the solution space consisting of millions of points

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